Quantum Holography in a 3n-Dimensional Multiverse: Emergent Geometry and Multipartite Wormholes from Entangled Qubit Boundaries

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May 26, 2026

The 't Hooft Holographic Principle fundamentally redefined the relationship between boundary and bulk, asserting that the information capacity of a spatial volume is strictly bounded by its enclosing area. In this paper, we extend this paradigm beyond standard cosmological models into a 3n-dimensional multiverse topology consisting of n distinct 3-dimensional universes. By replacing classical geometric boundaries—such as coincident spheres—with quantum discrete boundaries composed of entangled qubits, we resolve the dimensional mismatch inherent in product manifolds. We apply the It from Qubit framework and the ER=EPR conjecture to demonstrate how bulk geometry dynamically emerges from boundary entanglement. When the boundary qubits of these n universes share a highly entangled state, their entanglement entropy geometrically manifests as a multipartite wormhole. This central topological vertex allows the isolated universes to converge, creating a dynamically interconnected bulk. Through this translation of classical area into von Neumann entropy, we establish a theoretical framework where quantum decoherence equates to spacetime tearing, offering novel insights into the structural dependencies of higher-dimensional emergent spacetime, tensor networks, and quantum gravity.

Keywords: Holographic Principle, Quantum Information, Multipartite Entanglement, ER=EPR Conjecture, Emergent Spacetime, Tensor Networks, 3n-Dimensional Topology, Von Neumann Entropy, Quantum Gravity, Multiverse.

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1. Introduction to Quantum Holography in Higher Dimensions

The quest to reconcile general relativity with quantum mechanics has driven theoretical physics toward increasingly abstract paradigms, forcing a radical reevaluation of the fundamental nature of space, time, and information. For decades, the prevailing assumption was that spacetime served as a fundamental background arena in which physical processes unfolded. However, the study of black hole thermodynamics and string theory has heavily suggested that spacetime is not fundamental, but rather an emergent phenomenon. Central to this paradigm shift is the concept of quantum holography, which posits that the gravitational dynamics of a higher-dimensional bulk space can be entirely and equivalently described by a lower-dimensional theory existing on its boundary. While standard cosmological models often restrict themselves to four-dimensional spacetimes, string theory and advanced multiverse topologies regularly invoke higher-dimensional manifolds. Extending holographic concepts into these higher-dimensional spaces introduces severe geometric and topological challenges, particularly when attempting to define the boundaries of product manifolds. This paper explores the theoretical adaptation of holographic principles to a highly complex topology: a 3n-dimensional multiverse composed of n distinct three-dimensional universes. By transitioning from classical geometric boundaries to discrete quantum mechanical boundaries, we can resolve the dimensional mismatches inherent in such spaces and uncover novel mechanisms of emergent spacetime.

1.1. The Classical 't Hooft Holographic Principle

The origins of the holographic principle lie in the study of black hole thermodynamics, specifically the realization that the entropy of a black hole scales not with its volume, but with the surface area of its event horizon. This observation culminated in the Bekenstein-Hawking entropy formula, which states that the entropy S is equal to the area A divided by four times the gravitational constant G, in natural units where the speed of light and Planck's constant are set to one. The profound implication of this formula was recognized by Gerard 't Hooft, who generalized it into the holographic principle.

't Hooft proposed that the total information contained within any three-dimensional volume of space is strictly bounded by the two-dimensional surface area enclosing that volume. In a classical geometric sense, imagine a sphere filled with perfectly packed degrees of freedom. Traditional intuition dictates that the information capacity should grow proportionally to the cube of the radius. The holographic principle, however, dictates that the maximum information capacity grows only with the square of the radius. If one attempts to pack more information into the volume than the boundary area allows, the region will collapse into a black hole, naturally restricting the accessible information to the surface area of the resulting event horizon.

This classical interpretation relies heavily on continuous geometric boundaries, such as two-dimensional spherical shells bounding three-dimensional volumes. However, when theorists attempt to scale this classical geometry into complex, multi-dimensional topologies—such as a bulk space formed by the Cartesian product of multiple distinct universes—the geometric scaling laws break down. The bounding surface of a product manifold does not possess enough dimensions to serve as a sufficient holographic screen for the total bulk volume. Thus, the classical version of 't Hooft's principle, constrained by continuous geometric areas, hits a mathematical wall when applied to intersecting multi-universe models.

1.2. The Shift to the It from Qubit Paradigm

To overcome the limitations of classical geometry, modern theoretical physics has increasingly adopted the framework often summarized as It from Qubit. This paradigm builds upon John Archibald Wheeler's earlier concept of It from Bit, which suggested that physical reality fundamentally arises from discrete binary choices or information. The contemporary translation recognizes that the universe is fundamentally quantum mechanical, meaning the fundamental unit of reality is not a classical bit, but a quantum bit, or qubit.

In this framework, space and time are no longer viewed as continuous fabrics. Instead, they are the macroscopic, emergent manifestations of microscopic quantum information and entanglement. Geometry itself is a byproduct of how qubits are entangled with one another. This shift conceptually transforms the holographic principle. We no longer look at the physical surface area of a boundary to determine the bulk's information capacity. Instead, we look at the quantum entanglement entropy of the boundary degrees of freedom. The classical area in the Bekenstein-Hawking formula is replaced by the von Neumann entropy formula, S = -Tr(rho ln rho), where rho represents the density matrix of the quantum state on the boundary.

This quantum holographic approach was most famously realized in the Anti-de Sitter/Conformal Field Theory correspondence, which rigorously demonstrated how a quantum field theory without gravity on a boundary can perfectly encode a gravitational bulk theory in one higher dimension. Through tools like tensor networks, physicists can mathematically weave bulk spacetime out of boundary entanglement. The It from Qubit paradigm liberates holography from the constraints of continuous geometric areas, allowing theorists to define boundaries simply as abstract networks of interacting qubits.

1.3. Scope and Objectives of the Paper

This paper aims to bridge the gap between higher-dimensional multiverse topologies and quantum information theory by adapting the holographic principle to a specific theoretical framework. We will investigate a 3n-dimensional multiverse generated by the intersection of n distinct three-dimensional universes. Our primary objective is to demonstrate how replacing

classical boundary structures, such as coincident continuous spheres, with a discrete network of entangled qubits resolves the topological dimensional mismatch that typically plagues product manifolds.

We will first define the geometry and dimensional hurdles of the proposed 3n-dimensional bulk space. We will then mathematically translate the classical boundary conditions into quantum boundary conditions, mapping classical area to von Neumann entropy. By invoking the equivalence of quantum entanglement and spacetime geometry, we will illustrate how multipartite entanglement among the n distinct universes generates a central topological vertex, effectively weaving a dynamically emergent 3n-dimensional bulk.

Furthermore, the paper will explore the specific topology of multipartite wormholes that arise from this configuration, analyzing how the mutual information between boundary qubits constrains bulk connectivity and cross-universe communication. Finally, we will examine the physical consequences of quantum decoherence in this model, demonstrating that the loss of boundary entanglement translates directly to spacetime tearing and the topological isolation of the constituent universes. Through this comprehensive framework, we seek to provide a novel perspective on emergent geometry, higher-dimensional tensor networks, and the fundamental mechanics of quantum gravity in a multi-universe architecture.

2. Topological Architecture of the 3n-Dimensional Multiverse

To rigorously apply quantum holographic principles beyond standard cosmological bounds, we must first establish a precise mathematical foundation for the multiverse in question. In popular discourse, the term multiverse often evokes imagery of disconnected bubble universes expanding in an inflationary void, or the branching timelines of the many-worlds interpretation of quantum mechanics. The topological architecture explored in this paper diverges from those models. Instead, we are constructing a highly structured, geometrically integrated product space. This architecture demands a careful definition of how isolated spatial manifolds can be mathematically combined to form a higher-dimensional bulk, how their coordinate systems align, and how their boundaries interact at a shared point of convergence. By defining the topological parameters of this space, we set the stage for understanding the specific dimensional hurdles that necessitate a quantum mechanical, rather than classical, approach to holography.

2.1. Defining the n Distinct 3-Dimensional Universes

The fundamental building blocks of our proposed multiverse are n distinct, independent spatial manifolds. For the purposes of this theoretical framework, we denote each individual universe as U_i, where the index i ranges from 1 to n. Each U_i is modeled locally as a continuous 3-

dimensional spatial manifold, mathematically isomorphic to R^3 in its uncurved state. This means that an observer existing entirely within universe U_1 would experience a standard three-dimensional reality governed by the standard laws of physics, complete with its own localized fields, particles, and metric tensor determining local distances and curvature.

Crucially, in the absence of bulk entanglement, these n universes are completely causally disconnected and isolated from one another. The local coordinate system of U_1, defined by spatial axes x_1, y_1, and z_1, has no bearing on the local coordinate system of U_2, defined by x_2, y_2, and z_2. From the internal perspective of any given universe, the other n-1 universes are mathematically orthogonal and physically imperceptible. There is no classical trajectory or standard model interaction that allows matter or information to leak from one universe into another. They exist as independent, self-contained spatial arenas, each possessing its own vacuum energy state and cosmological evolution, operating entirely unaware of the broader multiverse structure they constitute.

2.2. Coordinate Origins and Coincident Boundaries

While these n universes are distinct and physically isolated from a classical standpoint, our architecture requires them to be topologically related to allow for the exploration of multi-boundary holography. To achieve this, we impose a global coordinate alignment such that all n universes share a single, localized point of intersection. We define a global origin point, mapping the coordinate (0,0,0) in U_1 to the exact same mathematical vertex as the coordinate (0,0,0) in every other U_i.

Around this shared global origin, we define our hypothetical holographic screens. Within each individual universe U_i, we construct a 3-dimensional local volume V_i centered on the origin. This volume is enclosed by a continuous 2-dimensional boundary surface, initially conceptualized as a classical geometric sphere, S^2_i, possessing a uniform radius r. Because these n spherical boundaries are all perfectly centered on the identical shared origin point across their respective orthogonal subspaces, they are termed coincident boundaries. They do not overlap or intersect in the traditional three-dimensional sense, as they occupy entirely different sets of spatial dimensions. However, from the perspective of the overarching mathematical space, they form a multi-dimensional cross-section, a complex union of surfaces radiating outward from a single point of absolute convergence. These coincident boundaries are the structures we will later transition from classical continuous areas to discrete quantum mechanical qubit networks.

2.3. The Nature of the Bulk Manifold

When the n distinct 3-dimensional universes are considered collectively as a unified geometric system, they generate the overarching space known as the bulk manifold, denoted as M. The

topology of this bulk manifold is rigorously defined by the Cartesian product of its constituent spaces: $M = U_1 \times U_2 \times ... \times U_n$. Because each individual universe contributes exactly three independent spatial dimensions to the product, the resulting bulk manifold M is inherently a 3n-dimensional space.

The nature of this bulk space is defined by extreme orthogonality. The spatial dimensions of U_1 are perpendicular to the spatial dimensions of U_2, which are in turn perpendicular to U_3, and so on throughout the entire structure. The global metric of the bulk manifold M is constructed by combining the individual metric tensors of all n universes. If no gravitational or quantum interactions bridge the gaps between the universes, the bulk space remains a purely mathematical construct—a flat, uncoupled hyper-space where the universes merely intersect at the shared zero-point origin like infinitely thin, perfectly rigid branes. However, the core thesis of this paper hinges on what occurs when the coincident boundaries defining these spaces become entangled. As we will explore, introducing multipartite quantum entanglement at the boundaries dynamically alters the nature of the bulk manifold, transforming it from a static, uncoupled Cartesian product into a deeply integrated, gravitationally active 3n-dimensional spacetime.

3. The Dimensional Hurdle of Product Manifolds

A central premise of the holographic principle is the strict dimensional relationship between a bulk space and its bounding screen. In standard formulations, such as those applied to a theoretical universe enclosed by an infinite boundary or a localized region bounded by a black hole event horizon, the mapping of information is clear and geometrically unambiguous. A given volume of space, possessing D spatial dimensions, is perfectly bounded by a continuous surface possessing D-1 spatial dimensions. The mathematical translation between the bulk degrees of freedom and the boundary degrees of freedom relies on this precise dimensional step-down. However, when we attempt to adapt this principle to a highly structured multi-universe topology constructed through Cartesian products, the classical geometry breaks down. The intuitive assumption that the boundaries of individual universes can simply be multiplied together to form the boundary of the total bulk manifold leads to a severe mathematical contradiction, exposing a fundamental limitation in classical geometric holography.

3.1. Calculating Boundary Dimensions in Cartesian Products

To understand why classical holography fails in our proposed 3n-dimensional multiverse, we must first examine the topological rules governing the boundaries of product manifolds. In standard topology, if one takes two manifolds, A and B, each possessing its own boundary, denoted as dA and dB, the boundary of their Cartesian product, $A \times B$, is not simply the product

of their boundaries, dA x dB. Instead, the Leibniz rule for boundaries dictates that the total boundary is the union of the boundary of the first manifold crossed with the bulk of the second, and the bulk of the first crossed with the boundary of the second. Mathematically, this is expressed as d(A x B) = (dA x B) U (A x dB).

When we scale this rule to our multiverse model, we encounter a strict dimensional requirement. The total bulk manifold M is constructed from the product of n distinct universes, U_1 x U_2 x ... x U_n. Because each individual universe U_i contributes exactly 3 spatial dimensions, the total dimensionality of the bulk manifold M is exactly 3n. Following standard holographic requirements, any continuous geometric boundary capable of enclosing and encoding the total information of this bulk must possess exactly 3n - 1 dimensions. The union of spaces generated by the Leibniz rule for boundaries mathematically satisfies this 3n - 1 dimensional requirement, creating a complex, multifaceted hyper-surface that completely encloses the 3n-dimensional volume.

3.2. Why Classical Coincident Spheres Fail as Holographic Screens

The geometric hurdle arises when we attempt to use the specific coincident boundaries defined in our architecture—the localized 2-spheres S^2_i located at the shared origin of each universe—as the holographic screen for the entire bulk. If we propose that the total information of the bulk is encoded strictly on the product of these localized spherical boundaries, we must calculate the dimensionality of that specific product space: S^2_1 x S^2_2 x ... x S^2_n.

Because each individual spherical boundary is a 2-dimensional surface, the Cartesian product of n such spheres generates a manifold possessing exactly 2n spatial dimensions. We can now directly compare this to the required boundary dimensions for the bulk. Standard holography demands a boundary of 3n - 1 dimensions. Our coincident spherical boundary provides only 2n dimensions.

This creates a critical inequality: for any multi-universe system where n is greater than 1, 2n is strictly less than 3n - 1. For example, if we intersect two 3-dimensional universes (n=2), the total bulk space is 6-dimensional. Holography requires a 5-dimensional boundary. However, the product of their two localized coincident 2-spheres creates only a 4-dimensional surface. A 4-dimensional surface fundamentally lacks the geometric capacity—the surface area—required to encode the degrees of freedom of a 6-dimensional bulk volume without exceeding the classical Bekenstein-Hawking entropy bound, S <= A / 4G. The product of the spheres is simply too small; it represents a lower-dimensional topological defect rather than a complete bounding surface. Therefore, classical coincident spheres fundamentally fail as holographic screens in a product space.

3.3. The Necessity of a Quantum Mechanical Translation

The mathematical failure of continuous geometric boundaries in our 3n-dimensional topology dictates that we can no longer rely on physical surface area as the limiting factor for information capacity. The classical Bekenstein-Hawking formula, constrained by the geometric dimension of the screen, cannot bridge the gap between a 2n-dimensional intersection and a 3n-dimensional bulk. To preserve the concept of a multi-universe holographic principle, the boundary conditions must be radically redefined.

This absolute necessity drives the theoretical transition from classical geometry to quantum mechanics. By abandoning continuous spatial boundaries in favor of discrete quantum states, we remove the rigid geometric constraints of continuous manifolds. When the boundary is composed of qubits, its capacity to encode the bulk is not dictated by the spatial dimensions it occupies, but rather by the complexity of its Hilbert space and the vast permutations of its internal quantum states. The dimensional deficit of the 2n-dimensional intersection is overcome by mapping the geometric area to the von Neumann entropy of the quantum system. This crucial translation allows the boundary to exist mathematically at the localized origin of the multi-universe structure, while possessing the requisite information capacity to encode a far higher-dimensional bulk spacetime through the mechanics of quantum entanglement.

4. Transitioning Boundaries: From Classical Spheres to Qubit Networks

The mathematical failure of continuous geometry to provide a sufficient holographic screen in a 3n-dimensional product space forces a fundamental shift in how we conceptualize boundaries. We must transition from the macroscopic illusion of smooth spacetime to the microscopic reality of quantum information. This section details the theoretical mechanics of discretizing the coincident spheres, replacing the classical metric of surface area with the algebraic structure of qubit networks. By doing so, we redefine the boundary not as a physical membrane spanning geometric dimensions, but as a dense configuration of purely quantum states. This transition is the critical mathematical step required to bypass the 2n-dimensional geometric limit and establish a functional multi-universe holography.

4.1. Discretizing Space: Spheres to Qubits

To resolve the dimensional deficit, the continuous two-dimensional boundary S^2_i in each individual universe U_i must be discretized into a finite array of quantum two-level systems, or qubits. In the classical formulation of the holographic principle, a spherical boundary with a physical area A is assumed to hold a maximum of A / 4G bits of information, effectively conceptualizing the surface as a grid of Planck-scale pixels. In our quantum adaptation, we

replace these classical, geometrically bound pixels with an equivalent number of discrete qubits, denoted as N_i for each universe.

Through this discretization, the boundary of universe U_i ceases to be a continuous mathematical manifold and becomes a discrete quantum many-body system. Crucially, the information capacity of this boundary is no longer dictated by the geometric surface area it occupies in space, but by the mathematical dimensionality of the system's Hilbert space. For a system composed of N_i qubits, the total Hilbert space dimension is 2^(N_i). Because the dimension of the Hilbert space scales exponentially with the addition of discrete quantum elements, the boundary's capacity to encode complex bulk degrees of freedom vastly exceeds the polynomial scaling of classical geometric volumes. By concentrating this massive density of quantum states at the localized origin point of each universe, the sheer volume of potential information effectively bypasses the geometric constraints of the 2n-dimensional topological intersection. The boundary becomes an ultra-dense node of quantum computation.

4.2. Local Superposition Versus Non-Local Entanglement

The physical architecture of our proposed multi-universe model depends entirely on the specific quantum states occupying these discrete boundary networks. The determining factor in the bulk geometry is the distinction between local quantum superposition and non-local quantum entanglement. If the N_i qubits forming the boundary of universe U_1 exist in highly complex states of superposition, yet remain entirely unentangled with the qubits forming the boundaries of U_2 through U_n, the holographic encoding remains strictly local to each subspace. The density matrix describing the total boundary system across all universes would simply factorize into a tensor product of pure, unentangled states.

Physically, an absence of cross-universe entanglement means that while each universe possesses a localized quantum boundary capable of encoding its own internal 3-dimensional bulk, the overarching 3n-dimensional space remains uncoupled. The multiverse remains a collection of isolated, mutually invisible realms that merely share a mathematical coordinate origin. The bulk manifold M remains a static, gravitationally dead Cartesian product.

However, when non-local entanglement is introduced across the distinct boundary networks, the topological isolation is broken. If a qubit on the boundary of U_1 becomes entangled with a qubit on the boundary of U_2, their quantum states can no longer be described independently; they form a single, non-separable quantum system. In the context of quantum holography, this shared quantum information is not merely an abstract statistical correlation. It is the fundamental foundational fabric of spacetime itself. Entanglement spanning the orthogonal boundary networks acts as a gravitational bridge, dynamically knitting the isolated 3-dimensional spatial bulks together. The degree and complexity of this boundary entanglement

strictly dictate the spatial geometry and gravitational strength of the resulting higher-dimensional bulk connection.

4.3. Establishing the Quantum Boundary Conditions

To formally model this dynamically interconnected bulk, we must establish the precise quantum boundary conditions for the entire n-partite multi-universe system. The global boundary state is defined by a singular composite density matrix, rho, which encompasses the complete, combined Hilbert space of all N qubits across all n universes. This composite boundary can no longer be accurately conceptualized as a physical surface spanning a measurable distance. Instead, it must be treated as an abstract tensor network localized at the absolute point of intersection—the shared zero-point origin of the multi-universe structure.

The quantum boundary conditions dictate that all physical parameters of the emergent 3n-dimensional bulk are intrinsically encoded within the entanglement structure of this global density matrix. The exact configuration of the boundary's tensor network determines the large-scale physics of the bulk. Whether the boundary qubits are entangled in simple bipartite pairs, complex multipartite loops, or highly symmetric global states directly determines the curvature, the spatial connectivity, and the gravitational dynamics of the overarching 3n-dimensional manifold. By mathematically stripping away the continuous spatial dimensions of the boundary and reducing it to a pure quantum information network at the nexus of the multiverse, we successfully map the highly concentrated quantum degrees of freedom at the origin to the infinite dimensional permutations required to project and sustain a holographic 3n-dimensional spacetime.

5. Von Neumann Entropy as the Holographic Bound

The transition from a classical geometric boundary to a discrete quantum network necessitates a complete redefinition of how information is measured and bounded within our multi-universe topology. In classical holography, physical surface area acts as the absolute limit for information capacity. However, having established that the 2n-dimensional intersection of our coincident boundaries cannot geometrically enclose a 3n-dimensional bulk, we must discard spatial area as the limiting metric. Instead, we turn to quantum information theory. By redefining the holographic bound in terms of von Neumann entropy, we completely detach the information capacity of the boundary from its physical spatial dimensions. This section outlines the mathematical framework for this transition, detailing how density matrices in an n-partite quantum system provide the necessary mathematical architecture to encode higher-dimensional bulk dynamics.

5.1. Replacing Bekenstein-Hawking Area with Quantum Entropy

The classical Bekenstein-Hawking entropy formula, S = A / 4G, is fundamentally reliant on a continuous metric space where the area A is a measurable, physical quantity. This formulation implies that the degrees of freedom of a bulk space are literally projected onto discrete Planck-sized tiles on a bounding surface. When adapting holography to the It from Qubit paradigm, this literal geometric projection is replaced by an abstract informational mapping. The bounding surface is no longer measured by a ruler, but by the complexity of its quantum state. We mathematically execute this transition by replacing the geometric area A with the von Neumann entropy of the boundary's quantum state.

The von Neumann entropy is defined mathematically as S = -Tr(rho ln rho), where rho represents the density matrix of the quantum system and Tr denotes the trace operation. Unlike physical area, von Neumann entropy is a measure of our fundamental uncertainty about the exact microstate of a quantum system. In a holographic context, this entropy quantifies the maximum amount of information that can be stored within the correlations of the boundary qubits. By utilizing von Neumann entropy as the holographic bound, the capacity of the boundary to encode the bulk is determined entirely by the internal Hilbert space of the qubit network, entirely bypassing the geometric dimensional deficit of the 2n-dimensional intersection. The boundary does not need to physically surround the bulk; it only needs to possess a sufficiently massive quantum entropy to computationally project it.

5.2. Density Matrices in n-Partite Systems

To calculate this holographic entropy for our specific multi-universe architecture, we must analyze the quantum state of the entire boundary structure using the formalism of density matrices. The total boundary of the multiverse is an n-partite system, meaning it is composed of n distinct subsystems, each corresponding to the discrete qubit network located at the origin of a specific universe U_i. The global state of this entire multiverse boundary is described by a single, comprehensive composite density matrix, denoted as rho_global.

If the n universes are completely isolated, their boundary qubits are unentangled, and rho_global is simply the tensor product of the individual, pure density matrices of each universe. In this uncoupled state, the von Neumann entropy of the global system is zero, reflecting a complete lack of cross-universe information sharing, which corresponds perfectly to an absence of an interconnected 3n-dimensional bulk geometry. However, when the universes interact, the global state becomes entangled. To understand the localized holographic perspective from within a single universe U_i, we must calculate its reduced density matrix, rho_i.

The reduced density matrix rho_i is obtained by performing a partial trace over the degrees of freedom of all other n-1 universes in the multi-universe system. Mathematically, this is expressed as rho_i = Tr_not_i (rho_global). This mathematical operation effectively averages out the quantum information contained in the rest of the multiverse, leaving a mixed state that perfectly describes the boundary of U_i. The entanglement entropy of this specific universe is then calculated using the von Neumann formula on its reduced density matrix: S_i = -Tr(rho_i ln rho_i). This specific entropy value, S_i, dictates exactly how much bulk information universe U_i is sharing with the broader 3n-dimensional overarching space.

5.3. Calculating the Information Capacity of the Qubit Boundary

The true power of transitioning to von Neumann entropy lies in the exponential scaling of quantum information capacity. To determine if our discrete boundary can successfully encode a 3n-dimensional bulk, we must calculate its absolute maximum information limit. Let us assume that the localized boundary in each universe U_i is composed of N_i discrete qubits. The total number of qubits at the localized intersection of the entire multiverse is therefore the sum of all N_i, which we will denote as N_total.

The mathematical dimension of the total Hilbert space for this combined quantum boundary is strictly 2^(N_total). The maximum possible von Neumann entropy for any quantum system occurs when it is in a completely mixed state, meaning all possible microstates in the Hilbert space are equally probable. In this scenario, the maximum entropy is simply the natural logarithm of the total Hilbert space dimension, resulting in S_max = N_total * ln(2).

This calculation reveals why the quantum translation successfully overcomes the geometric hurdle outlined in previous sections. While the spatial dimensions of the coincident spheres were mathematically constrained to 2n, the maximum information capacity of the discretized qubit boundary scales exponentially with the number of qubits, utterly independent of spatial geometry. As long as N_total is sufficiently large, the total von Neumann entropy of the centralized quantum boundary network can comfortably exceed the entropy requirements necessary to project and encode the degrees of freedom of a macroscopic 3n-dimensional bulk spacetime. The limitation on bulk complexity is no longer a question of geometric dimensions, but strictly a limit on the number of available qubits and the depth of their entanglement.

6. The ER=EPR Conjecture in a Multi-Universe Framework

Having established that the capacity of our discretized boundary is mathematically bounded by von Neumann entropy rather than geometric area, we must now define the physical mechanism by which this quantum information generates bulk spacetime. The transition from abstract quantum states to tangible geometry relies on one of the most profound theoretical insights of

modern physics: the proposed equivalence between quantum entanglement and spacetime wormholes. This section explores how scaling this equivalence from standard bipartite systems to an n-partite multiverse topology fundamentally dictates the gravitational architecture of the 3n-dimensional bulk.

6.1. Reviewing the Bipartite Susskind-Maldacena Conjecture

To understand the multi-universe application, we must first ground our framework in the original Susskind-Maldacena conjecture, colloquially known as ER=EPR. Proposed by Juan Maldacena and Leonard Susskind, this principle posits a literal equivalence between the Einstein-Podolsky-Rosen paradox, which describes quantum entanglement, and Einstein-Rosen bridges, which are classical spacetime wormholes derived from general relativity. In its standard formulation, the conjecture asserts that two quantum systems that are highly entangled are physically connected by a topological bridge in the fabric of spacetime, even if they are separated by vast cosmic distances.

The most prominent example of this bipartite principle involves two black holes. If a pair of black holes are formed from particles that exist in a maximally entangled state, the ER=EPR conjecture dictates that the interior geometry of these black holes is connected by a non-traversable wormhole. The quantum entanglement on the microscopic scale physically manifests as macroscopic spatial connectivity. In this paradigm, spacetime is not a pre-existing vacuum in which entangled particles reside; rather, the entanglement is the fundamental threads that weave the spacetime metric together. The amount of entanglement, quantified by the von Neumann entropy, directly corresponds to the cross-sectional area of the Einstein-Rosen bridge connecting the two regions.

6.2. Scaling ER=EPR to n-Dimensional Product Spaces

The standard ER=EPR conjecture is inherently bipartite, modeling the geometric connection between two distinct points or regions within a single, continuous universe. Adapting this principle to our multiverse architecture requires scaling the conjecture to an n-partite system spanning across orthogonal manifolds. In our model, we are not dealing with two black holes separated by distance, but with n discrete qubit networks localized at the shared coordinate origin of n physically distinct, orthogonal 3-dimensional universes.

When we apply the ER=EPR equivalence to this topology, the isolated Cartesian product space undergoes a radical topological shift. If the qubit boundary of universe U_1 becomes entangled with the qubit boundary of universe U_2, the conjecture dictates that an Einstein-Rosen bridge must dynamically form to connect them. However, because U_1 and U_2 occupy completely orthogonal spatial dimensions, this wormhole cannot traverse standard 3-dimensional space.

Instead, the spacetime bridge must manifest within the overarching 3n-dimensional bulk manifold M.

As we scale this to include all n universes, the boundary conditions become an n-partite entangled state. The bipartite bridges scale into a complex web of spacetime connectivity. The entanglement across the multi-universe boundaries mathematically forces the formerly uncoupled, gravitationally dead bulk manifold to become dynamically active. The static mathematical intersection at the global origin is transformed into a physical gravitational nexus, woven together entirely by the quantum correlations of the boundary qubits.

6.3. The Equivalence of Entanglement and Spacetime Bridges

In this scaled framework, the degree of spacetime connectivity across the bulk is directly proportional to the density of entanglement shared among the universes. The mathematical equivalence relies on measuring the mutual information between any given pair of universes, U_i and U_j, within the overarching system. The mutual information quantifies the amount of entanglement shared specifically between these two boundaries, effectively measuring how much knowing the quantum state of U_i reveals about the quantum state of U_j.

Following the scaled ER=EPR conjecture, this mutual information directly translates into the geometric properties of the bulk spacetime bridging those two specific universes. A higher degree of mutual information necessitates a wider, more robust spacetime bridge spanning the orthogonal dimensions within the 3n-dimensional bulk. Conversely, if the mutual information between two universes approaches zero, the spacetime bridge pinches off, severing the geometric connection and rendering those specific universes physically isolated from one another within the bulk manifold.

The composite density matrix of the entire boundary, discussed in the previous section, therefore acts as the ultimate blueprint for the bulk topology. The myriad correlations encoded within the global von Neumann entropy do not simply represent abstract information; they are the exact geometric coordinates and curvature tensors of the 3n-dimensional spacetime. By equating the abstract entanglement of the localized boundary qubits with the physical formation of higher-dimensional spacetime bridges, the ER=EPR conjecture provides the precise mechanical link required to project a unified, active bulk from a discrete quantum intersection.

7. Emergent Geometry from Multipartite Entanglement

The mathematical equivalence between quantum entanglement and spacetime bridges provides the theoretical foundation for our 3n-dimensional topology, but it is the specific structure of that entanglement that dictates the precise shape, curvature, and scale of the

emergent bulk. In classical general relativity, mass and energy dictate the curvature of a pre-existing spacetime manifold. In the framework of quantum holography, however, spacetime does not pre-exist. Instead, the geometric manifold is dynamically woven into existence by the complex web of multipartite entanglement shared among the localized boundary qubits. This section details the mechanisms by which discrete quantum correlations at the intersection of our n universes mathematically project an interconnected, fully dimensional 3n-dimensional bulk, focusing on the role of tensor networks and the profound geometric implications of symmetric quantum states.

7.1. Tensor Networks and Spacetime Weaving

To accurately model the emergence of bulk geometry from localized boundary states, we employ the mathematical formalism of tensor networks. Originally developed as a computational tool in condensed matter physics to simulate complex many-body quantum systems, tensor networks have become a cornerstone of the It from Qubit paradigm. A tensor network provides a visual and mathematical representation of the entanglement structure within a quantum state. In this formalism, individual quantum states or qubits are represented as nodes, and the entanglement correlations between them are represented as lines or edges connecting these nodes.

In our multi-universe architecture, the n distinct localized boundary networks located at the shared coordinate origin serve as the foundational nodes of this tensor network. If there is no entanglement between the universes, the network consists simply of isolated clusters of nodes, yielding no geometric bulk connection. However, when the boundary qubits of universe U_1 become entangled with the qubits of universe U_2, a mathematical edge is drawn between their respective nodes. As this entanglement spreads across the n universes, the tensor network grows in complexity, forming a highly interconnected graph.

The profound insight of quantum holography is that this abstract tensor network is not merely a diagram of quantum correlations; it is a discretized skeleton of the bulk spacetime itself. The geometric distance between any two points in the emergent 3n-dimensional bulk is inversely proportional to the degree of entanglement between the boundary nodes that project them. A high density of entanglement edges in the tensor network weaves a tightly connected, low-curvature spatial geometry in the bulk. By mathematically scaling this discrete network toward the continuum limit, the abstract graphical connections smooth out into the continuous metric tensor of the 3n-dimensional manifold. Therefore, the spacetime of the bulk is literally woven out of the multipartite entanglement shared at the multi-universe intersection.

7.2. Symmetric Entanglement States and Geometric Projections

The specific topology of the emergent 3n-dimensional bulk is highly sensitive to the exact class of multipartite entanglement occupying the global boundary state. Because we are dealing with an n-partite system, the entanglement structures are vastly more complex than simple bipartite pairs. To understand how specific quantum states project specific bulk geometries, we can analyze highly symmetric multipartite states, such as the Greenberger-Horne-Zeilinger state and the W state.

If the boundary qubits across the n universes are placed into a generalized GHZ state, expressed mathematically as a superposition of all qubits being in the 0 state and all qubits being in the 1 state, such as $|GHZ\rangle = (|00...0\rangle + |11...1\rangle) / \sqrt{2}$, the resulting geometry is radically centralized. The GHZ state represents genuine n-partite entanglement that cannot be reduced to bipartite pairs. Holographically, this state projects a singular, massive, highly unified multi-partite wormhole—a central topological vertex in the 3n-dimensional bulk where all n universes converge symmetrically. If any single universe is measured and its boundary decoheres, the entire GHZ entanglement collapses, meaning the central multi-partite wormhole would instantly vanish, severing the geometric connection across the entire multiverse.

Conversely, if the global boundary state is modeled as a W state, where the system exists in a superposition of a single excitation distributed evenly across all n boundary networks, the entanglement is fundamentally pairwise. Holographically, a W state would not project a single centralized vertex. Instead, it would weave a distributed, web-like geometry within the 3n-dimensional bulk, consisting of numerous, weaker bipartite Einstein-Rosen bridges connecting the universes in a network structure. Unlike the GHZ-projected geometry, the loss of entanglement in one universe within a W state configuration would not immediately collapse the entire bulk topology; the remaining universes would retain their pairwise spacetime bridges. Thus, the internal algebra of the multipartite quantum state strictly dictates the architectural blueprint of the emergent multiverse.

7.3. The Dynamic Nature of the Emergent 3n-Dimensional Bulk

By establishing that the bulk geometry is a direct projection of the boundary's quantum state, we arrive at a critical conclusion: the 3n-dimensional bulk manifold M is not a static, immutable background. It is a highly dynamic, fluctuating geometric entity. Because the localized boundary networks are composed of quantum systems subject to the laws of quantum mechanics, their states evolve over time according to the Schrödinger equation, governed by a localized Hamiltonian operator.

As the local boundary qubits interact, undergo phase shifts, or experience unitary evolution, the entanglement structure of the global composite density matrix continuously shifts. Edges within

the tensor network may form, strengthen, weaken, or dissolve entirely. Because this tensor network constitutes the skeleton of spacetime, these microscopic quantum fluctuations manifest macroscopically as dynamic changes in the curvature, connectivity, and gravitational metric of the 3n-dimensional bulk.

This dynamic emergence resolves the static nature of the original Cartesian product space. The orthogonal universes are no longer rigid branes intersecting at a dead mathematical coordinate. They are living spaces, breathing their shared bulk geometry into existence through the relentless computational churn of their entangled boundaries. A sudden influx of entropy or a massive localized calculation at the boundary of U_1 will alter its entanglement relations with U_n, instantly sending gravitational ripples or restructuring the wormhole connections traversing the 3n-dimensional bulk. The spacetime of the multiverse is therefore entirely fluid, a macroscopic echo of the ceaseless quantum activity occurring at its dimensional nexus.

8. The Topology of Multipartite Wormholes

Having established that multipartite entanglement on the discrete quantum boundaries dynamically weaves a 3n-dimensional bulk, we must now examine the precise topological structures that emerge from this process. The geometric translation of n-partite entanglement does not merely produce a chaotic network of spatial threads; it generates highly specific, mathematically rigorous spacetime topologies. Central to this architecture is the concept of the multipartite wormhole. This structure is fundamentally distinct from classical conceptualizations of wormholes and requires advanced topological frameworks to accurately model. This section explores the geometric nature of these higher-dimensional connections, detailing the transition from bipartite tubes to complex intersecting manifolds, the physical characteristics of the central topological vertex where all n universes converge, and the mathematical models required to describe the metric of this unprecedented junction.

8.1. Moving Beyond Simple Einstein-Rosen Bridges

In classical general relativity and the standard bipartite ER=EPR conjecture, an Einstein-Rosen bridge is topologically relatively simple. It is typically modeled as a traversable or non-traversable throat connecting two distinct asymptotic regions of spacetime. Geometrically, if the entrances to the wormhole are spherical, the topology of the bridge itself is essentially a cylinder, mathematically described as $S^2 \times R$, where S^2 is the two-dimensional sphere and R represents the spatial distance through the throat. This architecture relies entirely on a one-to-one connection between two boundaries.

However, when scaling to our 3n-dimensional multiverse architecture, this bipartite cylindrical topology becomes grossly inadequate. We are not connecting two regions of a single space; we

are connecting n distinct, orthogonal 3-dimensional spaces. If we relied solely on standard bipartite bridges in an n-partite system, the bulk would resemble a disorganized cluster of isolated tubes crossing each other without truly integrating the entire overarching manifold. True n-partite entanglement, such as the GHZ state discussed previously, cannot be geometrically represented by a collection of isolated $S^2 \times R$ cylinders.

Instead, the multipartite wormhole manifests as a unified, higher-dimensional cobordism. It is a single, continuous spacetime manifold whose boundary is the disjoint union of the n localized boundary networks of the individual universes. Rather than a simple throat, the topology resembles a complex, multi-branched manifold spanning the 3n-dimensional bulk. The spatial cross-section of this wormhole is not a simple sphere, but a highly complex geometric surface whose dimensional properties and curvature are dictated entirely by the permutation symmetries of the n-partite quantum state. Moving beyond simple Einstein-Rosen bridges requires discarding the notion of a simple tunnel and embracing the concept of a dynamically woven, multi-directional spatial junction that simultaneously anchors n distinct gravitational realities.

8.2. The Central Topological Vertex of n Universes

The defining topological feature of the multipartite wormhole generated by highly symmetric entanglement is its central vertex. Because all n localized boundary networks are situated at the exact same shared mathematical coordinate origin across their respective orthogonal subspaces, the bulk spacetime woven by their entanglement naturally gravitates inward toward this absolute zero-point. The result is a central topological vertex within the 3n-dimensional bulk where the emergent geometries of all n universes mutually intersect and merge.

This vertex is not a mathematically smooth, flat region of spacetime. It represents the absolute nexus of gravitational and informational exchange for the entire multiverse. Because the spatial dimensions of the individual universes are orthogonal, their merging at this vertex creates a region of extreme, multidirectional spacetime curvature. An observer hypothetically stationed at this central node would not perceive a standard 3-dimensional reality; they would be embedded within a localized region of the full 3n-dimensional metric, subjected to the gravitational influences of all connected universes simultaneously.

The physical dimensions and traversability of this central vertex are strictly bounded by the holographic entropy limits established in earlier sections. The cross-sectional area of the junction mapping to any specific universe U_i is proportional to the entanglement entropy of its boundary, S_i. If the global system is in a maximally entangled state, the vertex is broad and deeply integrated, allowing massive geometric continuity across the bulk. If the entanglement begins to degrade, the geometry of the vertex sharpens, the curvature increases, and the spatial

volume of the junction shrinks, physically pinching the connection between the intersecting worlds.

8.3. Mathematical Models of the Intersection Node

Describing the precise spacetime metric of this central topological vertex requires adapting standard tools of differential geometry and general relativity to extreme n-partite conditions. The standard Einstein field equations must be applied not to a 4-dimensional spacetime, but to the full 3n+1 dimensional manifold (accounting for time). The primary mathematical challenge lies in formulating the junction conditions at the exact point of intersection.

In classical general relativity, the Israel junction conditions dictate how different spacetime metrics can be sewn together across a bounding surface, ensuring that the induced metric and extrinsic curvature remain mathematically consistent to prevent infinite stress-energy singularities. In our multi-universe model, we must apply n-dimensional generalizations of these junction conditions. The discrete tensor network of the entangled boundary qubits serves as the stress-energy tensor that smooths out the severe geometric discontinuity at the origin.

Advanced mathematical models for this node often rely on the mathematics of branched coverings and algebraic geometry. The vertex can be modeled as a branch point in a complex covering space, where tracing a closed loop around the origin in the 3n-dimensional bulk seamlessly transitions an observer from the metric of universe U_1 into the metric of universe U_2. Furthermore, by utilizing the Ryu-Takayanagi formula, which generalizes holographic entanglement entropy to higher dimensions, theorists can map the density matrix rho_global directly to a specific set of minimal surfaces extending into the 3n-dimensional bulk. These minimal surfaces mathematically define the exact shape and curvature of the central topological vertex, providing a rigorous geometric blueprint for the heart of the emergent multiverse.

9. Information Bottlenecks and Bulk Connectivity

The geometric manifestation of multipartite wormholes provides a fascinating architectural blueprint for a connected multiverse, but a purely topological description is insufficient to understand the physical dynamics of such a system. If these n universes are physically connected by an emergent 3n-dimensional bulk, we must address the mechanics of interaction. Can an event in universe U_1 causally affect an observer in universe U_2? To answer this, we must transition from studying static geometry to analyzing the flow of quantum information. The physical traversability of the bulk spacetime is entirely dictated by the bandwidth of the quantum boundary. This section explores how quantum mutual information imposes strict geometric constraints on the bulk, the theoretical mechanics of signal propagation across orthogonal dimensions, and the fundamental bounds on cross-universe communication.

9.1. Mutual Information as a Geometric Constraint

In standard spacetime manifolds, the capacity for physical objects or information to pass through a specific region is constrained by the physical dimensions of that region, such as the cross-sectional area of a wormhole throat. In our quantum holographic framework, this geometric bottleneck is entirely dictated by the quantum mutual information shared between the localized boundaries. Mutual information mathematically quantifies the total amount of correlation, both classical and quantum, existing between two separate subsystems. For any two specific universes in our architecture, U_A and U_B, their mutual information is calculated as $I(A:B) = S_A + S_B - S_{AB}$, where S_A and S_B are the individual von Neumann entropies of their respective boundaries, and S_{AB} is the joint entropy of the combined system.

This mathematical value, $I(A:B)$, serves as a strict and unbreakable geometric constraint on the emergent 3n-dimensional bulk. According to holographic principles, the mutual information bounds the maximum cross-sectional area of the spacetime bridge connecting U_A and U_B within the central topological vertex. If the boundary qubits of U_A and U_B share maximal entanglement, $I(A:B)$ is large, projecting a broad, stable spacetime bridge. However, if the mutual information is low, the bulk geometry pinches, creating a severe informational bottleneck. The geometry dynamically restricts itself to ensure that the physical flow of bulk information can never exceed the quantum correlations mathematically encoded at the boundary intersection. The tensor network simply will not weave a spacetime conduit larger than the mutual information allows.

9.2. Signal Propagation Across the Multiverse Bulk

If a sufficiently broad spacetime connection exists, we must then formulate the mechanism by which a physical signal could theoretically propagate from one distinct 3-dimensional universe to another. Because the universes are dimensionally orthogonal, a particle cannot simply fly out of U_1 and enter U_2 through standard continuous spatial translation. Instead, signal propagation in this architecture functions analogously to complex quantum teleportation, mediated by the emergent bulk geometry.

For a physical state in U_1 to influence U_2, the information must first propagate to the shared coordinate origin of U_1. Upon interacting with the localized boundary network of N_1 qubits, the physical state is absorbed and scrambled into the global density matrix of the boundary structure. This process of scrambling maps the localized 3-dimensional information into the highly complex, non-local entanglement structure of the overarching n-partite state.

From the perspective of the bulk manifold M, this scrambling at the boundary represents the signal entering the multipartite wormhole. The information propagates through the 3n-dimensional spacetime by traversing the discrete nodes of the tensor network. To reconstruct

the signal in U_2, the boundary network of U_2 must possess sufficient entanglement with U_1 to decode the scrambled state. If the necessary mutual information exists, the localized quantum network at the origin of U_2 can re-project the information back into a localized physical state within its own 3-dimensional spacetime. Thus, what appears as a continuous journey through a higher-dimensional bulk is mathematically equivalent to the scrambling, transmission, and decoding of quantum information across an n-partite entangled boundary.

9.3. Bounds on Cross-Universe Communication

The strict reliance on mutual information imposes absolute upper limits on the nature and volume of cross-universe communication. Just as the Bekenstein bound limits the entropy within a standard volume of space, holographic theorems place a cap on the channel capacity of emergent wormholes. The physical influence one universe can exert upon another is entirely bottlenecked by the availability of shared boundary qubits.

If the localized boundaries consist of a finite number of discrete qubits, the maximum mutual information is fundamentally capped. Every bit of classical information or qubit of quantum information successfully transmitted from U_1 to U_2 physically degrades the entanglement resources of the boundary. Unless there is a mechanism to continuously pump entanglement back into the global boundary state, the act of cross-universe communication inherently shrinks the mutual information, physically narrowing the bulk wormhole with every transmitted signal.

Furthermore, if the mutual information bottleneck is extremely tight, macroscopic objects or complex structured signals cannot survive the bulk traversal. The information capacity would only allow for the passage of highly compressed, low-energy quantum noise. In this scenario, while the universes remain technically connected through the 3n-dimensional bulk, the connection is too narrow to allow for meaningful causal interaction. Observers within U_1 and U_2 would experience each other merely as faint, unreadable background radiation emanating from their shared coordinate origin, permanently isolated not by distance, but by the strict mathematical limits of quantum channel capacity.

10. Spacetime Tearing: Decoherence as Geometrical Severing

The realization that bulk geometry is an emergent property of boundary entanglement inherently introduces a profound vulnerability to the structure of the 3n-dimensional multiverse. In classical general relativity, spacetime is highly robust; it requires immense concentrations of mass and energy to significantly warp the metric, and topology changes—such as the severing of a wormhole—often require exotic matter or result in severe mathematical singularities. However, in the quantum holographic framework, the fabric of spacetime is only as stable as the quantum correlations that weave it. Because multipartite

entanglement is notoriously fragile, the higher-dimensional bulk connecting our n universes is a highly precarious geometric structure. This section explores the catastrophic geometric consequences of quantum decoherence, detailing how environmental interactions at the localized boundaries translate directly into the physical severing of spacetime, ultimately resulting in the topological isolation of the constituent universes.

10.1. Environmental Interaction and the Loss of Entanglement

To understand the mechanics of spacetime tearing, we must examine the boundary networks not as perfectly closed systems, but as physical structures existing within their respective local environments. The N_i qubits that comprise the boundary of universe U_1 are localized at its spatial origin. Therefore, they are continuously exposed to the internal physical dynamics of that specific 3-dimensional universe. They can interact with local electromagnetic fields, thermal radiation, stray particles, and gravitational waves propagating strictly within U_1.

According to the principles of quantum mechanics, entanglement is strictly monogamous. If a localized boundary qubit heavily entangled in the global n-partite state undergoes a physical interaction with a localized photon inside U_1, it will become entangled with that photon. Because quantum correlations cannot be infinitely shared, forming this new, local entanglement fundamentally requires breaking the non-local entanglement it shared with the boundary qubits of U_2 through U_n. This process is known as quantum decoherence.

As the localized boundaries interact with the thermal baths of their respective macroscopic universes, the intricate tensor network spanning the orthogonal dimensions begins to fray. The global composite density matrix, rho_global, which previously represented a highly unified, pure entangled state, rapidly degrades into a mixed state. The quantum information essential for sustaining the bulk geometry leaks into the local environments of the individual universes. Consequently, the mutual information I(A:B) shared between any two given universes plummets. In a multi-universe architecture, decoherence is not merely the loss of computational phase; it is the active dissolution of the structural integrity of the 3n-dimensional bulk.

10.2. The Physical Mechanism of Wormhole Pinching

The loss of mutual information triggers a dramatic and immediate topological phase transition within the bulk manifold. As established in the scaled ER=EPR framework, the geometric cross-section of the spacetime bridges converging at the central topological vertex is strictly constrained by the available entanglement entropy. When decoherence actively reduces this entropy, the geometric dimensions of the multipartite wormhole are forced to contract.

From the perspective of the tensor network, the mathematical edges connecting the boundary nodes of U_1 to U_2 are systematically deleted as their shared correlations vanish. Because

these edges represent discrete units of spatial distance and connectivity, their removal causes the emergent spacetime to sharply warp. The broad, deeply integrated geometric vertex connecting the universes begins to narrow. The extrinsic curvature at the multi-dimensional intersection intensifies rapidly, effectively pulling the orthogonal spaces apart.

As the mutual information approaches zero, the wormhole experiences a physical pinching off. In classical gravity, the snapping of a spacetime bridge typically generates a naked singularity, a point of infinite curvature where the laws of physics completely break down. However, the It from Qubit paradigm gracefully resolves this singularity. The spacetime does not tear in a violent, mathematically intractable explosion. Instead, the bulk geometry smoothly disintegrates back into unentangled quantum states. The discrete minimal surfaces defined by the Ryu-Takayanagi formula simply shrink to zero area. The continuous cobordism connecting the spaces evaporates, resulting in a clean, strictly topological severing of the higher-dimensional gravitational bridge.

10.3. Topological Isolation of the 3-Dimensional Universes

The ultimate endpoint of complete boundary decoherence is absolute topological isolation. Once the localized environments of the n universes have fully scrambled and absorbed the boundary information, the global composite density matrix factorizes entirely. It becomes a simple tensor product of n completely independent, localized mixed states. With zero mutual information shared across the dimensional boundaries, the tensor network weaving the bulk ceases to exist.

At this precise moment, the overarching 3n-dimensional bulk manifold loses all physical, dynamic reality. It instantly reverts from a dynamically active, gravitationally connected hyperspace back to a static, uncoupled mathematical Cartesian product. The multipartite wormhole at the central vertex is entirely gone, leaving behind n separate, perfectly smooth 3-dimensional spatial origins with no higher-dimensional spatial continuity between them.

For an observer within any individual universe U_i, this geometric severing would be virtually imperceptible on a macroscopic scale. The localized boundary at their coordinate origin would cease to function as an informational window into a wider multiverse, becoming nothing more than a localized source of randomized quantum noise. The universe U_1 is once again causally closed, physically sealed, and fundamentally blind to the existence of U_2 through U_n. Thus, the multi-universe architecture demonstrates a profound cosmological lifecycle dictated by quantum information: the multiverse is born from the initial generation of multipartite entanglement, sustained by the preservation of mutual information, and permanently dismantled by the relentless onset of quantum decoherence.

11. Implications for Quantum Gravity and String Theory

The theoretical framework constructed in this paper—where a 3n-dimensional bulk spacetime emerges from the multipartite entanglement of localized qubit boundaries—extends far beyond a simple cosmological thought experiment. By successfully translating the holographic principle from continuous geometry to discrete quantum information across orthogonal spaces, this model provides a novel testing ground for some of the most persistent problems in modern theoretical physics. Specifically, it offers profound implications for our understanding of quantum gravity and string theory. By redefining how higher-dimensional manifolds intersect and how information is conserved across complex topologies, this n-partite holographic architecture provides new mathematical pathways for resolving singularities, addressing information paradoxes, and expanding the established boundaries of the AdS/CFT correspondence.

11.1. Intersecting Brane Models Revisited

In standard string theory and M-theory, the fundamental constituents of reality are not merely one-dimensional strings, but multi-dimensional membranes known as D-branes. A common feature of advanced string phenomenologies is the intersecting brane model, where multiple branes of varying dimensions intersect within a higher-dimensional bulk space. The intersection loci of these branes are often where standard model physics is theorized to localize, with the intersecting geometry dictating the exact properties of the fundamental particles. However, classical geometric models of intersecting branes often struggle with mathematical singularities at the exact point of intersection, where the curvature and energy density theoretically diverge to infinity.

The quantum holographic architecture proposed in this paper offers a direct resolution to these intersecting brane singularities. If we treat our n distinct 3-dimensional universes as 3-branes occupying a 3n-dimensional bulk, their shared coordinate origin represents the ultimate brane intersection. By replacing classical, continuous geometric boundaries at this intersection with discrete networks of entangled qubits, we effectively quantize the intersection defect. The singularity is smoothed out by the tensor network.

Because the geometry of the intersection is bounded by the von Neumann entropy of the discrete localized boundary networks, infinite curvature is mathematically impossible. The maximum curvature of the central topological vertex is strictly limited by the finite dimension of the combined Hilbert space. Furthermore, the physical properties of the fields localized at the intersection are no longer dictated by classical geometric angles, but by the specific permutation symmetries of the n-partite entanglement state. This suggests that the fundamental constants and particle properties localized on intersecting branes in string theory

could be derived directly from the quantum information constraints of the underlying tensor networks weaving their junction.

11.2. Resolutions to Bulk Information Paradoxes

One of the defining challenges of quantum gravity is the black hole information paradox, which questions whether quantum information that falls into a gravitational singularity is permanently destroyed, violating the principle of unitary evolution. This problem is closely related to bulk reconstruction paradoxes in holographic theories, where physicists struggle to mathematically map deep bulk regions—especially those hidden behind event horizons or complex topological vertices—back to the boundary field theory.

Our n-partite multiverse model provides a robust framework for tracking information through extreme gravitational topologies. In this architecture, any physical information that traverses from universe U_1 into the emergent 3n-dimensional bulk is mathematically equivalent to that information being scrambled into the global density matrix of the boundary qubits. The central topological vertex, despite being a region of extreme, multidirectional curvature where n universes merge, does not possess an independent geometric reality that can hide or destroy information.

Because the entire bulk, including the complex central node, is a rigorous mathematical projection of the boundary tensor network, the information is always perfectly conserved within the unitary evolution of the n-partite quantum state. The von Neumann entropy bound ensures that the bulk wormhole can never absorb more information than the combined boundaries can computationally encode. Therefore, if an observer in U_1 sends a quantum state into the nexus, it is not lost to a higher-dimensional void. It simply undergoes highly complex quantum scrambling across the entangled boundary networks. As long as the global boundary state evolves unitarily, the information is perpetually conserved in the entanglement structure, theoretically allowing it to be perfectly reconstructed or decoded by an observer possessing access to the mutual information of the multiverse boundaries.

11.3. Future Avenues for Multi-Boundary AdS/CFT Correspondences

The most rigorous mathematical realization of the holographic principle is the Anti-de Sitter/Conformal Field Theory correspondence, which maps a gravitational theory in an AdS bulk to a quantum field theory without gravity on its asymptotic boundary. Standard AdS/CFT models typically involve a single continuous boundary encoding a single bulk geometry. While multi-boundary wormhole solutions exist in the literature—such as those connecting multiple distinct asymptotic regions of AdS space—they traditionally operate within the same dimensional framework, mapping multiple 2-dimensional boundaries to a single 3-dimensional bulk.

The architecture outlined in this paper proposes a radical expansion of the AdS/CFT dictionary by forcing the integration of orthogonal spaces. A critical avenue for future research will be formalizing the exact Conformal Field Theories that must exist on these intersecting localized boundaries. Because the boundaries are situated at the coordinate origin of their respective macroscopic universes, they are fundamentally distinct from the asymptotic boundaries at spatial infinity used in standard AdS/CFT.

Future mathematical models must define how the n-point correlation functions of n distinct, highly entangled CFTs—each operating within completely isolated, orthogonal spatial coordinates—can mathematically merge to compute the scattering amplitudes and metric tensors of a 3n-dimensional bulk. This will require the development of new classes of tensor networks capable of handling severe dimensional step-ups and extreme multipartite symmetries. If this multi-boundary, multi-dimensional correspondence can be rigorously defined, it would represent a monumental leap in holographic duality, proving that quantum information can stitch together not just regions of a single space, but entirely distinct dimensional realities into a unified gravitational whole.

12. Conclusion

The exploration of higher-dimensional multiverse topologies fundamentally challenges our classical intuitions regarding space, geometry, and information. Traditional cosmological models rely heavily on continuous spatial manifolds and the physical dimensions they occupy. However, as theoretical physics pushes toward a unified theory of quantum gravity, it becomes increasingly clear that classical geometry is an insufficient language for describing the fundamental architecture of reality. By adapting the 't Hooft Holographic Principle to a highly structured 3n-dimensional multiverse, this paper has demonstrated that the insurmountable geometric limitations of product spaces can be elegantly resolved through the application of quantum information theory. The transition from classical boundaries to quantum networks does not merely fix a mathematical dimensional deficit; it radically redefines the ontological nature of spacetime itself.

12.1. Summary of the Adapted Holographic Framework

The central hurdle addressed in this framework is the dimensional mismatch inherent in Cartesian product manifolds. When n distinct 3-dimensional universes intersect at a shared localized origin, their classical coincident boundaries—conceptualized as 2-dimensional spheres—generate a 2n-dimensional intersection. Standard geometric holography dictates that a 3n-dimensional bulk requires a 3n - 1 dimensional bounding surface. Because 2n is strictly less

than 3n - 1 for any multi-universe system, continuous geometric boundaries physically lack the spatial area required to encode the overarching bulk degrees of freedom.

To preserve the holographic principle, we established a strict mathematical translation. We discarded the physical surface area of the coincident spheres and replaced it with the von Neumann entropy of discrete qubit networks localized at the shared coordinate origin. By utilizing the formula S = -Tr(rho ln rho), the information capacity of the boundary became entirely decoupled from its spatial dimensions. Instead, it scaled exponentially with the dimension of the composite Hilbert space. This quantum translation proved that a localized, infinitely dense informational node possesses the mathematical capacity to perfectly project and encode a vastly larger, higher-dimensional macroscopic bulk space, successfully bypassing the geometric constraints that cripple classical multi-universe models.

12.2. The Fundamental Role of Entanglement in Cosmology

This adapted framework places quantum entanglement at the absolute center of cosmological architecture. By scaling the bipartite ER=EPR conjecture to an n-partite system, we established that the isolated 3-dimensional universes do not physically interact through standard spatial traversal. Instead, their overarching 3n-dimensional bulk is dynamically woven into existence by the complex web of multipartite entanglement shared among their discrete boundaries. The static mathematical intersection of orthogonal spaces is transformed into a living, gravitationally active multipartite wormhole, entirely sustained by the mutual information distributed across the global boundary state.

Furthermore, this model highlights the inherent fragility of emergent spacetime. Because the bulk geometry is a direct macroscopic projection of microscopic quantum correlations, it is highly susceptible to the mechanics of quantum decoherence. As localized boundary qubits interact with their distinct environmental thermal baths, non-local entanglement degrades into local mixed states. We demonstrated that this localized decoherence triggers a massive topological phase transition in the bulk, causing the geometric cross-sections of the connecting wormholes to physically pinch off. The ultimate fate of such a multiverse is not necessarily a gravitational collapse, but a clean, topological severing, resulting in the permanent informational and causal isolation of its constituent universes. In this paradigm, entanglement is not merely a curious phenomenon occurring within spacetime; it is the fundamental mortar holding the dimensional structure together.

12.3. Final Thoughts

The transition from the classical 't Hooft principle to the It from Qubit paradigm represents one of the most profound conceptual shifts in modern physics. By applying this paradigm to extreme topological architectures, we uncover deep underlying symmetries between quantum

computation and general relativity. The theoretical 3n-dimensional multiverse detailed in this paper serves as a rigorous testing ground for the limits of tensor networks, the resolution of intersecting brane singularities, and the future expansion of the AdS/CFT correspondence across orthogonal boundaries.

Ultimately, this adapted framework suggests that the universe—or any multi-universe structure—is not fundamentally composed of empty space and energetic matter. At its lowest, most irreducible level, reality is composed of pure quantum information. The continuous geometric fabric we perceive, complete with its gravity, its dimensions, and its vast cosmic distances, is merely a holographic shadow cast by the relentless computational churn of entangled qubits at the boundaries of existence. As we continue to probe the depths of quantum gravity, it is highly probable that the ultimate laws of the cosmos will be written not in the language of curved geometry, but in the precise, discrete algebra of quantum information theory.

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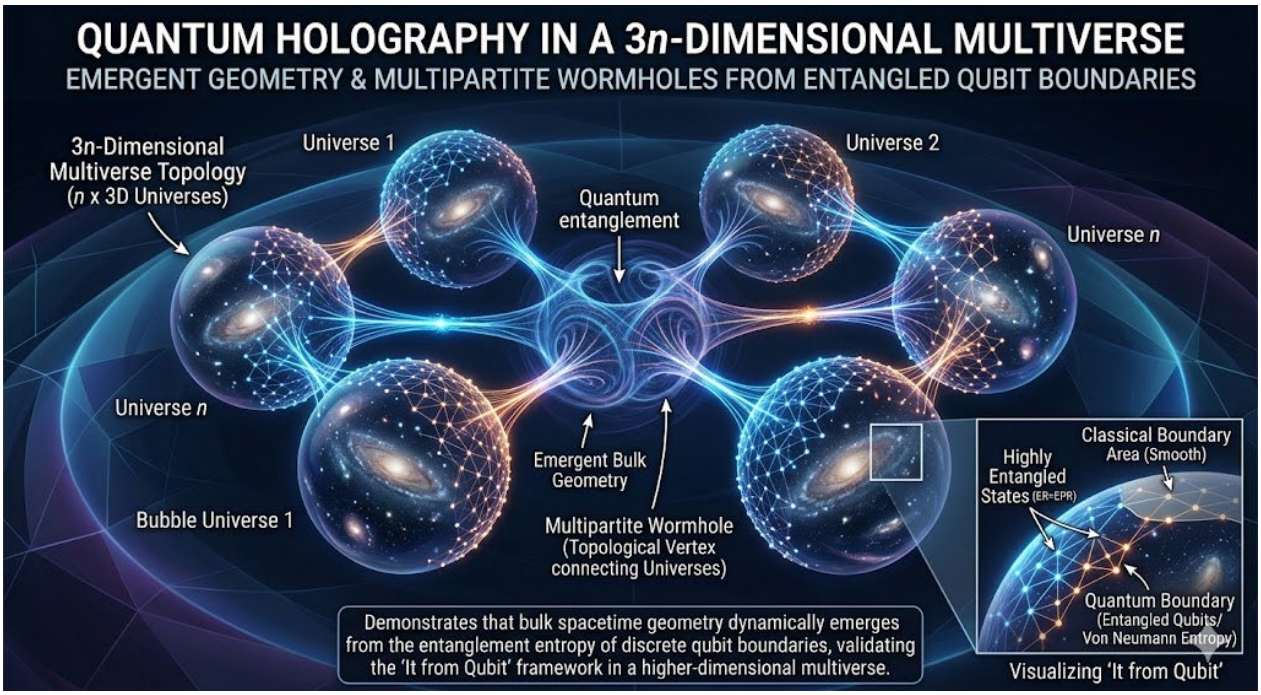
The author has published over 5,500 AI-assisted papers at: https://www.researchgate.net/profile/Douglas-Youvan/research . Google Scholar has indexed these preprints, and if you want a particular reference, the AI mode of a Google search (Gemini) has efficiently catalogued these preprints.


QUANTUM HOLOGRAPHY IN A 3n-DIMENSIONAL MULTIVERSE
EMERGENT GEOMETRY & MULTIPARTITE WORMHOLES FROM ENTANGLED QUBIT BOUNDARIES
3n-Dimensional Multiverse Topology (n x 3D Universes)
Universe 1
Universe 2
Quantum entanglement
Universe n
Universe n
Emergent Bulk Geometry
Bubble Universe 1
Multipartite Wormhole (Topological Vertex connecting Universes)
Classical Boundary Area (Smooth)
Highly Entangled States (ER=EPR)
Quantum Boundary (Entangled Qubits/ Von Neumann Entropy)
Demonstrates that bulk spacetime geometry dynamically emerges from the entanglement entropy of discrete qubit boundaries, validating the 'It from Qubit' framework in a higher-dimensional multiverse.
Visualizing 'It from Qubit'